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A Mixed Integer Programming for Port Anzali Development Plan

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***Abstract*—**This paper introduces a mixed integer programming model to find the optimum development plan for port Anzali. The model minimizes total system costs taking into account both port infrastructure costs and shipping costs. Due to the multipurpose function of the port, the model consists of 1020 decision variables and 2490 constraints. Results of the model determine the optimum number of berths that should be constructed in each period and for each type of cargo. In addition to, the results of sensitivity analysis on port operation quantity provide useful information for managers to choose the best scenario for port planning with the lowest investment risks. Despite all limitations-due to data availability-the model offers a straightforward decision tools to port planners aspiring to achieve optimum port planning steps.

***Keywords*—**MILP, Multipurpose Terminal, Port Operation Optimization, Port Anzali.

I. INTRODUCTION

DUE to the importance of marine transportation infrastructures in financial situation of Iran, great emphasis should be put on investment in marine terminals of the country. Port Anzali is one of the greatest northern ports of Iran. By loading various types of cargo along with its special geographic location, the port plays a significant role in connecting Iran's northern neighbors (Russia, Turkmenistan, Azerbaijan, and Kazakhstan) to its southern neighbors and also to open seas [5]. Previously MILP models were used for port planning in container terminals [1], [4], in this paper the purpose is to formulate an investment model to find an optimum development plan for a multipurpose port, which has more complexities than an exclusive port. In the following sections the methodology of the study, model parameters and results of the model are explained and finally a discussion over the study results is stated.

II. METHODOLOGY

As the objective of the study is to find optimum development plan for port, current status of port and its operation statistics including port statement of facts, cargo handling efficiency, available facilities, etc should be gathered and studied. Then, modeling parameters (decision variables, related costs and benefits, cargo trade network constraints, budget limitations, operational limitations, etc) are defined. Eventually, the results are evaluated by sensitivity analysis and the optimum solution considering port situation is proposed.

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III. MODELLING

A. Port Operation Quantity

Generally four types of cargo are planned to be handled via Anzali Port: general cargo, Ro-Ro, crude oil and container. The estimated port operation is demonstrated in table I [6].

TABLE I
ESTIMATED PORT OPERATION QUANTITY

Cargo Type	Year	
	2010	2016
Container (TEU)	107127	147004
General cargo(ton)	4807053	6177487
Ro-Ro (ton)	17510	22513
Oil (ton)	1106700	1720000

Export: 44%.
Import: 56%

B. Objective Function

The objective function which is to minimize the total system costs from national point of view. The related formula are as follows:

$$G = MIN\ (Z). \quad (1)$$

Where Z is :

$$Z = C_{trans} + C_{fac} + C_{const} + C_{dredge} + C_{oper} - B \quad (2)$$

$C_{transportation}$: denotes the net present value of transportation costs, this item will differ according to the ship size and capacity. Fig.1 illustrates the relation between transportation costs and ship sizes.

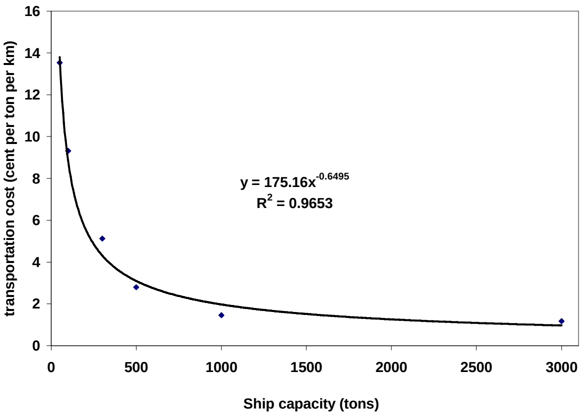

Fig. 1. Transportation Cost of different ships [9]

K.Cullinane and M.Khanna have carried out a research about the economics of scale of large container ships, the transportation cost of container ships are assumed based on the results of their study [2].

C_{fac} : denotes the net present value of facilities that should be purchased for berths.

C_{const}: denotes the net present value of construction costs of different structures for port development.

C_{dredge}: denotes the net present value of dredging cost required to deepen the seabed for larger vessels.

C_{oper}: denotes the net present value of annual costs that will be paid annually in port.

B: denotes the net present value of benefits gained by tariffs of different ship types.

All above mentioned parameters are functions of decision variables.

C. Constraints

I) Cargo demand constraints are as follows:

$$\sum_{ir} Sh_{icrn} \times UnloadingQuantity_i \geq D_{cn} \tag{3}$$

Sh : Integer variable used to model the number of ships.

i : denotes ship type based on ship capacity, Ship capacities are assumed to be 1000, 3000, 5000 and 7000 tons in this study.

c : Cargo type.

r : Transportation route.

n : Year.

D : Cargo demand value.

$UnloadingQuantity_i$: Cargo quantity that should be unloaded from ship type i.

II) Cargo supply constraints are as follows:

$$\sum_{ir} Sh_{icrn} \times loadingQuantiity_i \leq S_{cn} \tag{4}$$

S : Cargo supply value.

$loadingQuantity_i$: Cargo quantity that should be loaded to ship type i.

III) Port Capacity constraints are as follows:

$$\sum_c a_{5c} Sh_{5cn} \leq Br_{5cn} (broccup)_c \times 350$$

$$\sum_c \left(a_{5c} Sh_{5cn} + a_{4c} Sh_{4cn}\right) \leq \left(Br_{5cn} + Br_{4cn}\right)(broccup)_c \times 350 \tag{5}$$

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a_{ic} : Days that i-th ship type carrying cargo type c requires for loading and unloading operations at berth.

Br_{icn} : An integer variable used to model the number of berths.

$broccup$: Denotes berth occupancy, this factor depends on the number of berths; therefore, it is calculated by trial and error methods.

Port working days assumed to be 350 days in a year [7].

IV) Integer constraints:

$$\sum_r y_{icnr} \leq sh_{ircn}$$

$$\sum_r sh_{ircn} \leq K \sum_r y_{ircn} \tag{6}$$

y : 0-1 integer variable used to model the either-or situation.

K : A large positive number [3].

V) Cargo trade network of port Anzali

$$\sum_i Sh_{icrn} \times LoadingQuantity_i \leq \exp_r \times S_{nc}$$

$$\sum_i Sh_{icrn} \times UnloadingQuantity_i \geq imp_r \times D_{nc} \tag{7}$$

$\exp_r$: The percentage of cargo that must be exported from port via r –th route.

imp_r : The percentage of cargo that must be imported from origin port via r –th route.

IV. Results

The output of the model determines the number of berths that should be constructed in 2010 and 2016 in port Anzali for handling different types of cargo.

Since the project is a governmental project, the interest rate is assumed to be 10 percent; the life time of port facilities is considered to be 15 years while the life time for berth and structures is assumed to be 25 years [7].

Due to the relationship between berth occupancy factor and number of berths [8], trial and error method is used to determine berth occupancy factor for different types of berths.

At first trial the berth occupancy assumed to be 50 percent for all types of berths, based on the first trial results, new values are assigned to berth occupancies and the model is run for the next time and so on. After doing 5 trials the final calculated berth occupancies for 4 types of the cargo are as follows:

Ro-Ro: %40
General cargo:%70
Container: %55
Oil:%45

In following section the result tables of port development are presented.

A. *Optimum investment Steps*

Required number of berths and berth length for years 2008, 2010 and 2016 are demonstrated in tables II to IV. In these tables berth type1 denotes berths which are suitable for ships with the maximum capacity of 1000tons, berth type2 for ships with the maximum capacity of 3000tons, berth type3 for ships with the maximum capacity of 5000tons, berth type4 for ships with the maximum capacity of 7000tons, berth type5 for ships with the maximum capacity of 10000tons.

TABLE II
REQUIRED NUMBER OF BERTHS IN PORT ANZALI (2008)

Berth type	Cargo type			
	General cargo	Container	RO-RO	Oil
Berth type1	2	0	1	0
Berth type2	2	0	0	0
Berth type3	5	1	0	1
Berth Length (meter)	1181	155	75	155

TABLE III
REQUIRED NUMBER OF BERTHS IN PORT ANZALI (2010)

Berth type	Cargo type			
	General cargo	Container	RO-RO	Oil
Berth type1	2	0	1	0
Berth type2	2	0	0	0
Berth type3	5	2	0	1
Berth type4	1	0	0	0
Berth Length (meter)	1357	310	75	155

TABLE IV
REQUIRED NUMBER OF BERTHS IN PORT ANZALI (2016)

Berth type	Cargo type			
	General cargo	Container	RO-RO	Oil
Berth type1	2	0	1	0
Berth type2	2	0	0	0
Berth type3	6	3	0	2
Berth type4	1	0	0	0
Berth type5	1	0	0	0
Berth Length (meter)	1704	465	75	310

Based on the result tables, the investor should construct 2 berths with the length of 155 and 175 meters for general cargo and 1 berth with the length of 155 meters for containers by 2010 (Although one more berth for Ro-Ro is required, Ro-Ro and tankers can be served by common berth at first interval). In the next interval, the investor should construct 2 more berths with the length of 155 meters and 190 meters for general cargo, 1 more berth with the length of 155 meters for container, 1 more berth with the length of 155 meters for tankers and 1 more berth with the length of 75 meters for Ro-Ro by 2016.

B. *Port Layout*

According to the Table III and Table IV, Fig.2 and Fig.3 are recommended as the most appropriate port layouts for 2010 and 2016.

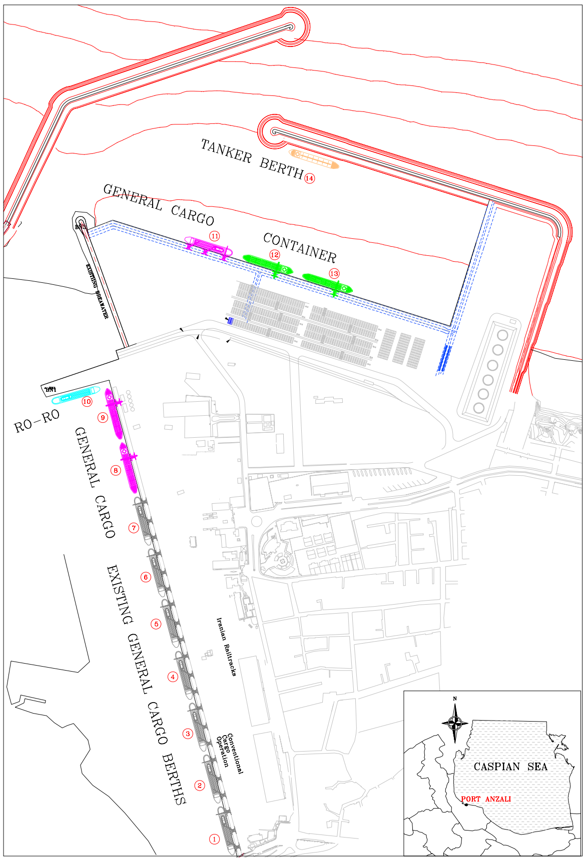

Fig. 2. Proposed port layout for 2010

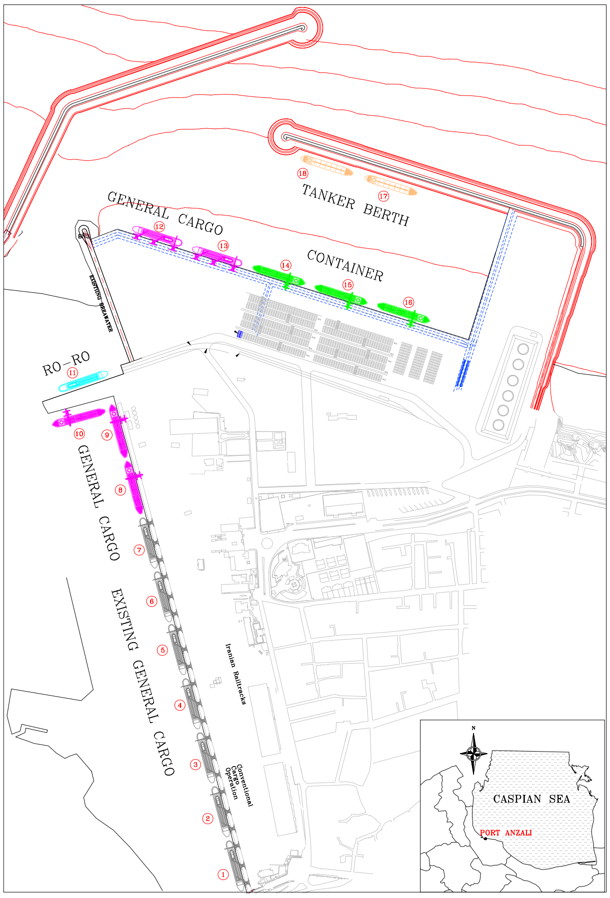

Fig.3. Proposed port layout for 2016

V. Disscussion

Due to various uncertainties in determining the exact quantity of port operation, sensitivity analysis is done on the amount of cargo that should to be handled. Tables V-VI demonstrate the output of the model when the ratio of actual port operation to the estimated port operation (Table I) changes in the following intervals:

$$(r = \frac{Actual\ port\,operation}{Estimated\ port\,operation})$$

I- 1.05 < r <1.3
II- 0.95< r <1.05
III- 0.85< r < 0.95
IV- 0.75< r <0.85

TABLE V
Sensitivity Analysis Results (2010)

Scenario	r			
	1.05 - 1.3	0.95 - 1.05	0.85 - 0.95	0.75 - 0.85
Req. No. general cargo berth	13	10	9	9
Req. No. container berth	3	2	1	1
Req. No. tanker berth	2	1	1	1
Req. No. Ro-Ro berth	1	1	1	1
Req. general cargo berth length	1757	1357	1282	1255
Req. container berth length	438	310	155	155
Req. tanker berth length	283	155	155	128
Req. Ro-Ro berth length	155	75	75	75
Total berth length (meter)	2633	1897	1667	1613

TABLE VI
Sensitivity Analysis Results (2016)

Scenario	r			
	1.05 - 1.3	0.95 - 1.05	0.85 - 0.95	0.75 - 0.85
Req. No. general cargo berth	14	12	10	10
Req. No. container berth	4	3	3	1
Req. No. tanker berth	3	2	2	1
Req. No. Ro-Ro berth	1	1	1	1
Req. general cargo berth length	2008	1704	1474	1447
Req. container berth length	593	465	331	155
Req. tanker berth length	459	310	310	128
Req. Ro-Ro berth length	155	75	75	75
Total berth length (meter)	3215	2554	2190	1805

VI. Conclusion

In this research by using operational research science an optimization model was formed where its objective function is to minimize the net present value of the investment on ports from national viewpoint.

Although marine terminals are so critical and require a large amount of investment, analyzing port development as an operational research problem is not common. In fact, investors use traditional methods to plan how to develop ports and increase their handling capacity. In this research, by using integer programming, the development stages for a multipurpose port are determined, the results of the formulated model determines how many berths for which type of cargo is required in each sub period.

Furthermore, sensitivity analysis is done on the estimated port operation quantity; the results of the sensitivity analysis would help investors to make proper decision in order to invest in port in the optimum way under any conditions. In case of data availability the model can be used for different marine terminals in the world.

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